Recent Progress on Charmonium Decays at BESIII *

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Abstract

In 2009, the BESIII experiment has collected about 225M J/ψ and 106M ψ' samples, both of which are the world largest on-peak charmonium production. Based on these dataset, BESIII has made great effort on the study of the charmonium decays, some important of which have been reviewed in this proceeding. In addition, a searching for new physics through the CP/P violation process is reported.

1 Introduction

BEPCII/BESIII is an upgrade facility from the previous BEPC/BES [1]. The collider experiment BESIII is monitoring the double-ring electron-positron head-on collisions produced by the BEPCII machine. The luminosity is optimized at a center-of-mass energy of 3.78 GeVand the peak record has reached to $6.4 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$, which luminosity is one order of higher than that at CESR-c [2]. The beam energy ranges from 1.0 GeV to 2.3 GeV. Therefore, the physics in BESIII cover the τ-charm physics.

The BESIII spectrometer [1] as shown in Fig. 1, consists of the following main components with order of the distance to the interaction position: a main draft chamber with momentum resolution 0.5% at 1 GeV; an electromagnetic calorimeter with energy resolution 2.5% at 1.0 GeV; a Time-Of-Flight counters; a superconducting magnet with a field of 1 T; a muon chamber system made of resistive plate chambers.

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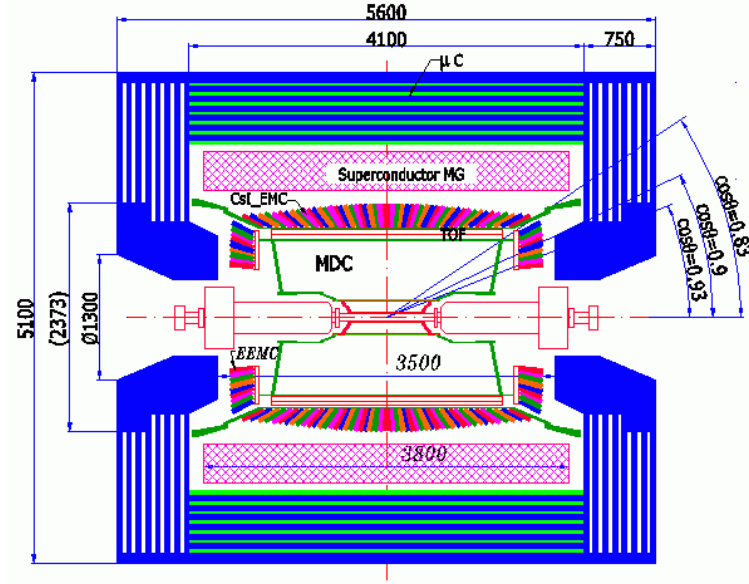

Figure 1: An Overview of the BESIII Detector.

dataset, BESIII has made great effort on the study of the charmonium decays, some important of which have been reviewed in this proceeding. In addition, a search for new physics through the CP/P violation process is reported.

2 Study of Radiative Decays $\psi' \to \gamma + P(P = \pi^0, \eta, \eta')$

The radiative decay of the ψ' to a pseudo-scalar meson provide important tests for various mechanisms in understanding the low-Q^2 phenomena, such as the vector meson dominance model (VDM), the two-gluon coupling to $c\bar{c}$ states, the $\eta - \eta'$ mixing angle, the final-state radiation by light quarks. Recently, the CLEO-c Collaboration reported measurements for the decays of J/ψ, ψ', and ψ'' to γP [3], and no evidence for $\psi' \to \gamma\eta$ or $\gamma\pi^0$ was found.

BESIII studied the processes $\psi' \to \gamma\pi^0$ with $\pi^0 \to \gamma\gamma$, and $\psi' \to \gamma\eta$ with $\eta \to \pi^+\pi^-\pi^0[\pi^0\pi^0\pi^0]$, and $\psi' \to \gamma\eta'$ with $\eta' \to \gamma\pi^+\pi^-$. The analyses use the 106M ψ' data sample. The results show that $\psi' \to \gamma\pi^0$ and $\psi' \to \gamma\eta$ are observed for the first time with significance of 4.6σ and 4.3σ, respectively, and with branching fractions of $\mathcal{B}(\psi' \to \gamma\pi^0) = (1.58 \pm 0.40 \pm 0.13) \times 10^{-6}$ and $\mathcal{B}(\psi' \to \gamma\eta) = (1.38 \pm 0.48 \pm 0.09) \times 10^{-6}$. Branching fraction of the process $\psi' \to \gamma\eta'$ is measured with improved accuracy to be $\mathcal{B}(\psi' \to \gamma\eta') = (126 \pm 3 \pm 8) \times 10^{-6}$. The mass distributions of the pseudoscalar meson candidates are shown in Fig. 2. For the first time, BESIII determined the ratio of the η and η' production rates from ψ' decays, $R_{\psi'} \equiv B(\psi' \to \gamma\eta)/B(\psi' \to \gamma\eta') = (1.10 \pm 0.38 \pm 0.07)\%$.

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This ratio is in agreement with 90% C.L. upper limit determined by CLEO-c and in contradiction to predictions of leading-order perturbative QCD. This is also smaller than the corresponding ratio for the J/ψ decays by an order of magnitude, which was measured to be $R_{J/\psi} = (21.1 \pm 0.9)\%$. More details on this study can be found in Ref. [4].
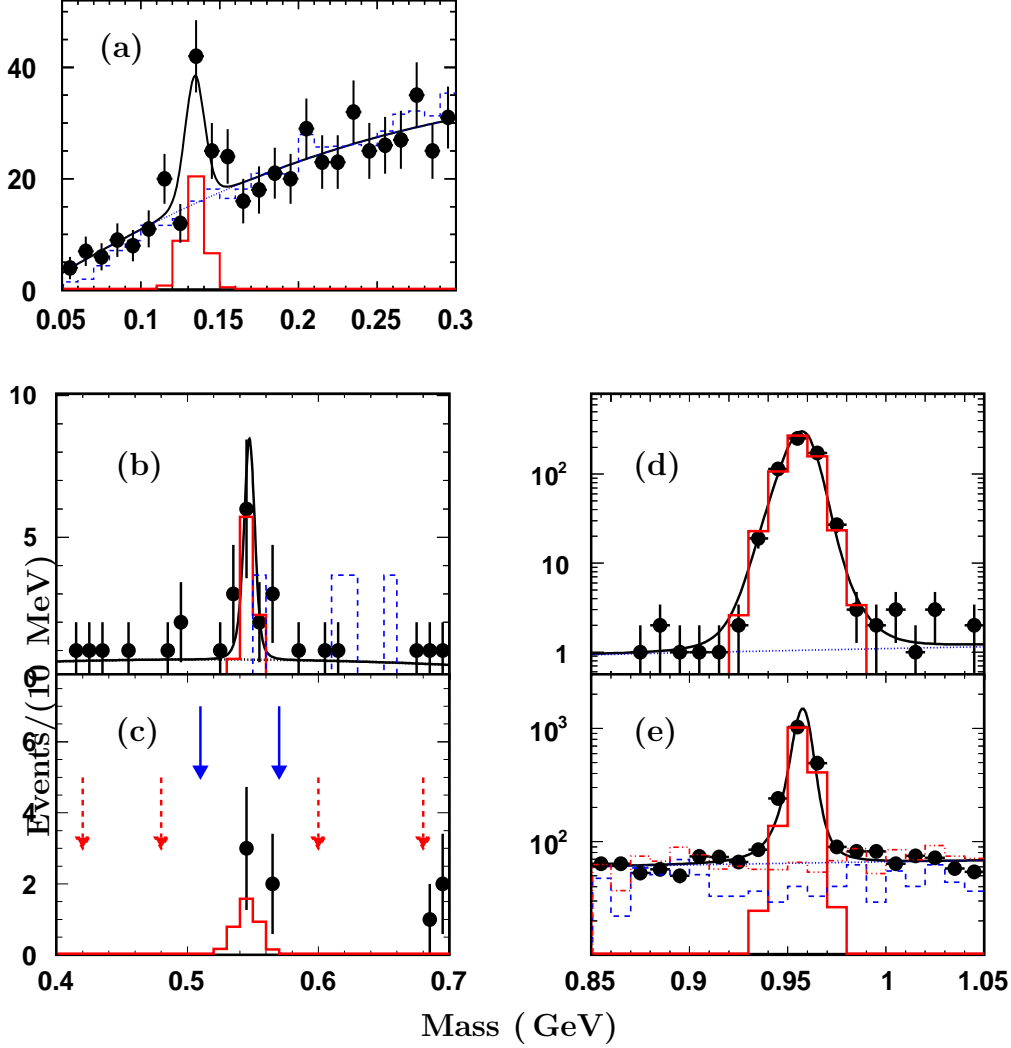

Figure 2: Mass distributions of the pseudoscalar meson candidates for $\psi' \to \gamma P$: a) $\gamma\pi^0$; b) $\gamma\eta(\pi^+\pi^-\pi^0)$; c) $\gamma\eta(3\pi^0)$; d) $\gamma\eta'(\pi^+\pi^-\eta(\gamma\gamma))$; e) $\gamma\eta'(\gamma\pi^+\pi^-)$. Refer to Ref. [4] for details.

3 Study of Hadronic Decays of χ_{cJ}

BESIII has world largest ψ' on-peak production, which endow BESIII with the largest radiative decay χ_{cJ} data. χ_{cJ} hadronic decay helps in understanding the P-wave charmo-

nium decay dynamics. Most of hadronic decay channels of χ_{cJ} are not still known and the pursued measurement provide a good laboratory to test the color singlet and octet mechanism in interpreting χ_{cJ} hadronic decays. At BESIII, χ_{cJ} decays to $PP(P = \pi^0, \eta)$ [5], $VV(V = \omega, \phi)$ [6], $\Lambda\bar{\Lambda}$ [7] and $4\pi^0$ [8] have been studied through $\psi' \to \gamma\chi_{cJ}$ decays.

The decay χ_{cJ} decays to $VV(V = \omega, \phi)$ were studied with ϕ reconstructed form K^+K^- or $\pi^+\pi^-\pi^0$, ω from $\pi^+\pi^-\pi^0$, and π^0 from $\gamma\gamma$. The results are shown in Table 1. The decays of $\chi_{c1} \to \phi\phi[\omega\omega]$, which were suppressed in helicity sum rule (HSR) [9], and the doubly OZI suppressed decay $\chi_{c0} \to \omega\phi$ are observed for the first time. Evidence for the $\chi_{c1} \to \omega\phi$ decay is found with a signal significance of 4.1σ. The branching fractions for $\chi_{c0[2]} \to \phi\phi[\omega\omega]$ decays are remeasured with improved precision. These precise measurements will be helpful for understanding χ_{cJ} decay mechanisms. In particular, the measured branching fractions for $\chi_{c1} \to VV$ indicate that HSR is significantly violated and that long distance effects play an important role in this energy region. Details about this study can be found in Ref. [6].

Table 1: Summary of the branching fractions ($\mathcal{B}$) for $\chi_{cJ} \to VV$ measured at BESIII [6]. Also listed are the world average in PDG [10]. The upper limit is estimated at the 90% C.L.

Mode	PDG $\mathcal{B}(\times 10^{-4})$	BESIII $\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \to \phi\phi$	9.2 ± 1.9	$8.0 \pm 0.3 \pm 0.8$
$\chi_{c1} \to \phi\phi$		$4.4 \pm 0.3 \pm 0.5$
$\chi_{c2} \to \phi\phi$	14.8 ± 2.8	$10.7 \pm 0.3 \pm 1.2$
$\chi_{c0} \to \omega\omega$	22 ± 7	$9.5 \pm 0.3 \pm 1.1$
$\chi_{c1} \to \omega\omega$		$6.0 \pm 0.3 \pm 0.7$
$\chi_{c2} \to \omega\omega$	19 ± 6	$8.9 \pm 0.3 \pm 1.1$
$\chi_{c0} \to \omega\phi$		$1.2 \pm 0.1 \pm 0.2$
$\chi_{c1} \to \omega\phi$		$0.22 \pm 0.06 \pm 0.02$
$\chi_{c2} \to \omega\phi$		< 0.2

Hadronic decay of χ_{cJ} to baryon pair has challenged the color octet mechanism, since many of baryon pair decays present disagreement between experimental measurements with theoretical calculations, in particular $\chi_{cJ} \to \Lambda\bar{\Lambda}$. BESIII studied the process $\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520)$ decaying to $p\bar{p}K^+K^-$ with results of $\mathcal{B}(\chi_{c0} \to \Lambda(1520)\bar{\Lambda}(1520)) = (3.18 \pm 1.11 \pm 0.53) \times 10^{-4}$, $\mathcal{B}(\chi_{c1} \to \Lambda(1520)\bar{\Lambda}(1520)) < 1.00 \times 10^{-4}$ and $\mathcal{B}(\chi_{c2} \to \Lambda(1520)\bar{\Lambda}(1520)) = (5.05 \pm 1.29 \pm 0.93) \times 10^{-4}$. This is the first measurement on the χ_{cJ} decays to excited baryon pairs. Details can be found in Ref. [7].

4   Study of Radiative Decays $\chi_{cJ} \to \gamma V (V = \rho, \omega, \phi)$

Doubly radiative decays of the type $\psi \to \gamma X \to \gamma\gamma V$, provide information on the flavor content of the C-even resonance X and on the gluon hadronization dynamics in the process [11]. For the case $X = \chi_{cJ}$, it may provide an independent window for understanding possible glueball dynamics and validating theoretical techniques. The vector meson of ρ, ω and ϕ were studied at BESIII.

Table 2 shows the numerical results, along with the theoretical predictions from perturbative quantum chromodynamics (pQCD) [12], nonrelativistic QCD (NRQCD) [13], and NRQCD plus QED contributions (NRQCD+QED) [13], and the results from the CLEO experiment [14]. We see the improved measurements at BESIII provide tighter constraints on theoretical calculations. Especially, we observe $\chi_{c1} \to \gamma\phi$ for the first time. In addition, the fraction of the transverse polarization component of the vector meson in $\chi_{c1} \to \gamma V$ decay is studied, which indicates the dominant longitudinal component. Details of this study can be found in Ref. [11].

Table 2: Measurements of $\mathcal{B}(\chi_{cJ} \to VV)$ (in units of 10^{-6}) at BESIII, and comparison of theoretical predictions and measurements at CLEO-c. The upper limits are at the 90% confidence level (C.L.).

Mode	BESIII	CLEO [14]	pQCD [12]	NRQCD [13]	NRQCD +QED [13]
$\chi_{c0} \to \gamma\rho^0$	<16.2	< 9.6	1.2	3.2	2.0
$\chi_{c1} \to \gamma\rho^0$	$25.8 \pm 5.2 \pm 2.3$	$243 \pm 19 \pm 22$	14	41	42
$\chi_{c2} \to \gamma\rho^0$	<8.1	< 50	4.4	13	38
$\chi_{c0} \to \gamma\omega$	<10.5	< 8.8	0.13	0.35	0.22
$\chi_{c1} \to \gamma\omega$	$228 \pm 13 \pm 22$	$83 \pm 15 \pm 12$	1.6	4.6	4.7
$\chi_{c2} \to \gamma\omega$	<20.8	< 7.0	0.5	1.5	4.2
$\chi_{c0} \to \gamma\phi$	<12.9	< 6.4	0.46	1.3	0.03
$\chi_{c1} \to \gamma\phi$	$69.7 \pm 7.2 \pm 6.6$	< 26	3.6	11	11
$\chi_{c2} \to \gamma\phi$	<6.1	< 13	1.1	3.3	6.5

5   Study of η_c' Decays into Two Vector Mesons

η_c' is only recently established in charmonium family and it's property is intriguing both in experiment and theory. The sizes of the decays of $\eta_c' \to VV$, where V stands for light vector mesons, are predicted to be highly suppressed under the mechanism of helicity selection rule (HSR). However, the effect from charmed meson loop mechanism can evade HSR effect, and enhance the production. Hence, the measurement of $\mathcal{B}(\eta_c' \to VV)$ may help in understanding the role played by charmed meson loops in $\eta_c \to VV$.

BESIII searched for the η_c' signls in three exclusive decay channels: $\psi' \to \gamma\rho^0\rho^0 \to \gamma 2(\pi^+\pi^-)$, $\psi' \to \gamma K^{*0}\bar{K}^{*0} \to \gamma\pi^+\pi^- K^+K^-$, and $\psi' \to \gamma\phi\phi \to \gamma 2(K^+K^-)$ [15]. As a

result, no obvious η'_c signal was observed. The upper limits are given as $\mathcal{B}(\eta'_c \to \rho^0\rho^0) < 3.1 \times 10^{-3}$, $\mathcal{B}(\eta'_c \to K^{*0}\bar{K}^{*0}) < 5.4 \times 10^{-3}$, and $\mathcal{B}(\eta'_c \to \phi\phi) < 2.0 \times 10^{-3}$. These upper limits are lower than the theoretical predictions. Details of this study can be found in Ref. [15].

6 Study of CP and P Violation through $P \to \pi\pi (P = \eta, \eta', \eta_c)$

In Standard Model (SM), CP and P violating process $P \to \pi\pi$ (P is a pseudoscalar meson) can proceed only via the weak interaction with a branching fraction of order 10^{-27}. Improved QCD only allow up to 10^{-15}. The decay rates of P and CP invariance process can be experimentally tested. Any higher level will trigger new physics beyond SM.

With world largest J/ψ on-peak data, BESIII searched for signals of the CP/P violating process $P \to \pi^+\pi^-[\pi^0\pi^0](P = \eta, \eta', \eta_c)$, via $J/\psi \to \gamma P$ decays. Table 3 lists the results for the upper limits on the branching fractions of all the processes studied. This measurement improves the world-best upper limits of the studied channels, except for $\mathcal{B}(\eta \to \pi\pi)$. These results provide experimental limits for theoretical models predicting how much CP and P violation there may be in η' and η_c meson decays. Details of this search are described in Ref. [16].

Table 3: Summary of the limits on $\eta/\eta'/\eta_c$ decays to $\pi^0\pi^0$ and $\pi^0\pi^0$ states. $\mathcal{B}^{\mathrm{UP}}$ is the upper limit at the 90% C.L. on the decay branching fraction of $\eta/\eta'/\eta_c$ to $\pi^+\pi^-$ or $\pi^0\pi^0$, and $\mathcal{B}^{\mathrm{UP}}_{PDG}$ is the upper limit on the decay branching fraction from PDG [10].

mode	$\mathcal{B}^{\mathrm{UP}}$	$\mathcal{B}^{\mathrm{UP}}_{PDG}$
$\eta \to \pi^+\pi^-$	3.9×10^{-4}	1.3×10^{-5}
$\eta' \to \pi^+\pi^-$	5.5×10^{-5}	2.9×10^{-3}
$\eta_c \to \pi^+\pi^-$	1.3×10^{-4}	6×10^{-4}
$\eta \to \pi^0\pi^0$	6.9×10^{-4}	3.5×10^{-4}
$\eta' \to \pi^0\pi^0$	4.5×10^{-4}	9×10^{-4}
$\eta_c \to \pi^0\pi^0$	4.2×10^{-5}	4×10^{-4}

7 Summary

We report the recent progress on the charmonium decays studied at BESIII, including ψ' radiative decays to a pseudoscalar meson, χ_{cJ} hadronic decays, χ_{cJ} radiative decays to a vector meson, and η'_c decays to vector meson pairs. In addition, the search effort for new physics through CP/P violation process, pseudoscalar meson decay to $\pi\pi$, is presented.

8 Acknowledgements

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